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Calculated Glasshouse Light Transmission

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Preliminary Results 1. : Glasshouse Orientation

Note. The contents of this paper are to be regarded as confidential until published by the authors.

A calculation for the estimation of solar radiation falling within a glasshouse has been described in Agricultural Memorandum No. 277. In order to test the calculation for internal consistency and agreement with measured results, the computer programme was applied in several example situations. A selection of the results obtained is given below, together with discussion on interpretation.

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1. The Timber Vinery

Because some previous measurements of transmission have been made on houses of this type, and many such houses are still in use, it seemed desirable to take one as a first example. The house chosen was one of the timber vineries at the Lee Valley E.H.S., measuring 130 H x 27.5 ft. and with 24 ins. glass. The house stands on a supporting wall 30 in. high. The overall height to the ridge is 156 in. and to the eaves 68 in. For calculation purposes the base wall is disregarded, and the light levels calculated are those which obtain at a height of 30 in. from the floor of the house, i.e. level with the lowest point of the transmitting structure. It is this level which is subsequently referred to as the "floor area".

Calculations were made for the house at 51° latitude, in E-W orientation (aspect 0°), and N-S orientation (90°) and at 15° intervals between these positions. The results were as follows:-

I. Direct Light

Direct Light: % transmission (Table 1)

North

| Aspect | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0° (E-W) | 56.7 | 60.9 | 61.9 | 57.9 | 59.0 | 59.1 | 59.5 | 57.7 | 60.4 | 62.0 | 59.1 | 55.6 |
| 15° | 56.6 | 60.8 | 61.1 | 58.4 | 59.4 | 61.7 | 61.8 | 59.5 | 59.4 | 61.8 | 59.0 | 55.6 |
| 30° | 56.2 | 59.4 | 58.2 | 59.6 | 62.8 | 63.7 | 63.7 | 62.6 | 59.5 | 56.9 | 58.1 | 55.0 |
| 45° | 53.8 | 55.3 | 57.4 | 62.6 | 64.6 | 65.2 | 65.1 | 64.4 | 61.9 | 55.3 | 54.7 | 53.1 |
| 60° | 49.1 | 51.4 | 59.6 | 64.2 | 65.9 | 66.2 | 66.1 | 65.7 | 63.3 | 54.7 | 49.8 | 48.1 |
| 75° | 44.6 | 49.2 | 60.9 | 65.1 | 66.4 | 66.8 | 66.7 | 66.1 | 64.4 | 56.5 | 46.7 | 43.1 |
| 90°(N-S) | 42 | 48.2 | 62 | 65.4 | 66.4 | 66.7 | 66.7 | 66.2 | 64.3 | 57.8 | 46.1 | 41.2 |

The results demonstrate clearly the advantage of E-W orientation (Aspect 0°) for transmission of direct light during winter. Unfortunately there are no recorded measurements with which they can be directly compared, but they support the general conclusions of Whittle and Lawrence (1) which have long been accepted. However, these detailed calculations demonstrate three additional important points:-

(a) Little of the advantage of E-W orientation of this house is lost by varying the orientation up to 30° from the E-W axis.

(b) The contribution of the south facing roof slope is at least equally important to that of the walls in producing the advantage of E-W orientation. (In this particular house the transmitting area of the long, south-facing wall is very



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small in relation to that of the roof, but the advantage of E-W orientation is still retained). The separate contribution of walls and roof slopes to the direct radiation reaching the house floor is shown below for the house in E-W and N-S orientations.

Total Direct Solar Radiation Reaching Floor (cals/day/$10^5$) (Table 2)

| Month | | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E-W,: | Roofs | 188 | 511 | 1300 | 2165 | 3149 | 3664 | 3184 | 2360 | 1875 | 921 | 370 | 136 |
| E-W,: | Walls | 98.7 | 141 | 217 | 232 | 240 | 219 | 197 | 199 | 231 | 183 | 136 | 83 |
| N-S,: | Roofs | 154 | 410 | 1318 | 2436 | 3597 | 4051 | 3499 | 3678 | 1998 | 874 | 300 | 113 |
| N-S,: | Walls | 62 | 106 | 201 | 269 | 328 | 330 | 288 | 258 | 243 | 155 | 96 | 51 |

(c) Whilst the percentage transmission of direct light is greatly influenced by orientation, the total amount of direct light in winter is low, and the proportion of direct/diffuse light is also low. A large increase in % transmission of direct light may therefore be relatively unimportant in practice. This point is further discussed at III, below.

2. Diffuse Light

Transmission of diffuse light is unaffected by orientation, and is a function of house structure only. The calculation method shows a small increase in diffuse light transmission in summer, due to increased reflection of light from surfaces surrounding the house, and transmission varies between 56% in midwinter and 57.3% in midsummer. The uniformity of diffuse light transmission throughout the year is in agreement with the measurements of Edwards and Lake, (2) and with Edwards (3), and the % transmission calculated agrees very closely with that measured by Edwards for similar houses at Efford and Fairfield as 55%.

III. Total Light

% Transmission of Total Light (Table 3)

| Aspect | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | F | M | A | M | J | J | A | S | O | N | D |
| 0° (E-W) | 56.3 | 57.9 | 58.9 | 57.4 | 58.1 | 58.2 | 58.1 | 57.2 | 58.5 | 58.8 | 57.5 | 55.8 |
| 15 | 56.4 | 57.9 | 58.6 | 57.6 | 58.3 | 59.4 | 59.2 | 58.0 | 58.0 | 58.8 | 57.6 | 55.9 |
| 30 | 56.1 | 57.4 | 57.4 | 58.1 | 59.9 | 60.4 | 60.0 | 59.3 | 58.0 | 56.8 | 57.2 | 55.7 |
| 45 | 50.9 | 55.9 | 57.0 | 57.0 | 60.8 | 61.1 | 60.7 | 60.1 | 59.1 | 56.1 | 55.8 | 55.1 |
| 60 | 53.9 | 54.5 | 57.9 | 60.1 | 61.4 | 61.6 | 61.2 | 60.6 | 59.7 | 55.9 | 53.9 | 53.6 |
| 75 | 52.5 | 53.7 | 58.5 | 60.5 | 61.6 | 61.8 | 61.4 | 60.8 | 60.2 | 53.9 | 52.6 | 52.0 |
| 90°(N-S) | 52 | 53.7 | 58.9 | 60.6 | 61.7 | 61.8 | 61.4 | 60.9 | 60.2 | 57.1 | 52.4 | 51.5 |

In the table above showing the variation of % transmission of all light by month and orientation, the effect of orientation on winter light transmission is still clearly seen. But whereas for direct light only in January, E-W orientation gives one third more transmission, for total light the gain is only 8-9%. This is because diffuse light transmission is not improved by orientation, and in this area of the country accounts for about 70% of the total light received in January.

Roughly comparable measurements for N-S houses at Efford and Fairfield by Edwards (3) show a range of transmission from "approximately 48% in mid-winter to 65% in mid-summer". The range in the calculation above is substantially smaller, from 51.5% to 61.8%. In part, Edwards wider range may be due to a higher proportion of direct radiation in these coastal areas. But additionally, Edwards measurements were made at a height of 11 ft. in the houses, i.e. above the level of the eaves and gutters. They were therefore largely a measure of the variation of transmission through the roof surfaces of the houses. For these roof surfaces our calculation shows that the seasonal variation of direct light transmission is very much greater than for the wall surfaces (it can be seen in table 2 that roof transmission in June is some twenty-six times that of January, whereas wall transmission is only about five times that of January). It is therefore to be expected that the seasonal range in the calculation will be smaller than in Edwards measurements, and as it relates to the light received at 30 ins. from the border soil rather than 11 ft., it probably approximates more closely to the light conditions at crop level, especially in winter.

These results also confirm the standard use of the transmission factor of 50% in winter and 60% in summer when computing glasshouse irrigation needs from outside solarimeter figures at the Lee Valley E.H.S.

For practical purposes, the total light energy received at the floor area is perhaps of greater value than the % transmission, and the computed figures are given below:-

Total Radiation Reaching Floor Area (cals/cm$^2$/day) (Table 4)

| Aspect | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | F | M | A | M | J | J | A | S | O | N | D |
| 0° (E-W) | 27.5 | 52.1 | 103 | 162 | 218 | 238 | 213 | 177 | 138 | 76 | 37.1 | 21.7 |
| 15 | 27.5 | 52.1 | 102.5 | 163 | 219 | 243 | 222 | 180 | 137 | 76 | 37.2 | 21.7 |
| 30 | 27.4 | 51.6 | 100 | 164 | 225 | 247 | 227 | 184 | 137 | 74 | 37 | 21.6 |
| 45 | 26.8 | 50.3 | 100 | 164 | 228 | 250 | 228 | 186 | 140 | 73 | 36 | 21.4 |
| 60 | 26.3 | 49 | 101 | 170 | 230 | 252 | 230 | 188 | 141 | 72 | 35 | 20.8 |
| 75 | 25.6 | 48 | 102 | 171 | 231 | 254 | 231 | 189 | 142 | 73 | 34 | 20.2 |
| 90° (N-S) | 25.3 | 48 | 103 | 171 | 231 | 254 | 231 | 189 | 142 | 74 | 34 | 20.0 |

Expressed in this way, the gain in light energy at floor level obtained by E-W rather than N-S orientation may appear small. In assessing its value, it may be useful to employ the approximation suggested by Canham, Cockshull and Hughes (unpubl) that 1 cal/cm$^2$ is roughly equivalent to 3360 lux hours (310 lumen/sq. ft./hrs.) from mercury fluorescent lamps. A level of 500 lumens/sq. ft. is often used for lettuce in growing rooms, and the gains shown above are roughly equivalent to supplementary illumination at this level for 1.2 hours daily in October, 1.9 in November, 1 hr. in December, 1.4 hrs. in January, and 2.5 hrs. in February.

It must also be remembered that this timber vinery, with a very small transmitting area in the walls, is not of a type expected to yield very great advantages from E-W orientation. Greater differences might be expected with a more modern design of house, such as is discussed below.

## 2. The Alloy Wide-Span House

Measurements of the transmission of E-W oriented wide-span houses have been described by Edwards and Lake (2) (3) in some detail: the house principally used was situated at Fernhurst, and its dimensions were - length 214 ft., width at eaves 63 ft., eaves

height 8 ft., ridge height 24 ft. Their results may be compared directly with the following results calculated for a house of very similar construction, also in latitude 51° and with similar cloudiness, and measuring 200 ft. length, 64 ft. width, 8 ft. eaves height, 23 ft. ridge height. The calculated results are as follows:-

I. Direct Light

Direct Light. % Transmission. (Table 5)

| Aspect | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0° (E-W) | 65.7 | 65.1 | 65 | 59.6 | 59.5 | 59 | 59.5 | 59.8 | 61 | 64.4 | 65.1 | 65.4 |
| 15 | 65.8 | 65.3 | 62.9 | 60.6 | 61.4 | 61.3 | 61.5 | 61.5 | 61.3 | 64.5 | 65.5 | 65.8 |
| 30 | 64.3 | 63.4 | 61.3 | 62.5 | 63.2 | 63.2 | 63.3 | 63.2 | 62.3 | 61.4 | 64.1 | 64.3 |
| 45 | 61.8 | 63.6 | 61.8 | 63.9 | 64.6 | 64.7 | 64.7 | 64.4 | 63.6 | 59.3 | 60.2 | 61.7 |
| 60 | 55.7 | 61.4 | 62.7 | 64.9 | 65.5 | 65.5 | 65.4 | 65.4 | 64.3 | 60.3 | 55.1 | 56.2 |
| 75 | 51.0 | 57.1 | 63.3 | 65.3 | 65.8 | 65.8 | 65.9 | 65.7 | 64.8 | 61.3 | 51.7 | 50.7 |
| 90° (N-S) | 49.7 | 57.7 | 63.4 | 65.6 | 65.8 | 65.8 | 65.8 | 65.7 | 64.9 | 62.3 | 50.6 | 48.7 |

The transmission of direct light by this type of house shows very similar variations by season and orientation to those given by the timber vinery. Transmission of direct light is of course greater, especially during the winter months. Edwards and Lake measured a transmission of 57% in summer and 68% in winter for their similar house, which compares closely with the 59% and 65.7% shown above, for the house in aspect 0°.

II. Diffuse Light

Transmission of diffuse light in this house is much improved by the reduction amount of opaque structure, and the calculated % transmission varies between 71.7% in winter and 73.4% in summer. The value given by Edwards and Lake for a similar house was 69%, again in very close agreement.

III. Total Light

The calculated transmission of total light for this house is given in table 6 below. Edwards and Lake, on the basis partly of measurement and partly of calculation, give transmissions of 63% in summer and 68% in winter for their example house. These compare with the figures of 66.4% in June and 69.8% in December for the house below in E-W orientation.

% Transmission of Total Light. (Table 6)

| Aspect | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0° (E-W) | 69.8 | 69.6 | 68.9 | 67.0 | 66.8 | 66.4 | 66.9 | 67.2 | 67.7 | 69.2 | 69.5 | 69.9 |
| 15 | 69.8 | 69.7 | 68.6 | 67.5 | 67.7 | 67.6 | 67.8 | 67.9 | 67.8 | 69.2 | 69.7 | 69.9 |
| 30 | 69.4 | 69.0 | 67.9 | 68.3 | 68.5 | 68.5 | 68.6 | 68.7 | 68.2 | 67.9 | 69.1 | 69.4 |
| 45 | 68.6 | 67.4 | 67.1 | 69.0 | 69.2 | 69.2 | 69.2 | 69.2 | 68.8 | 67.1 | 67.5 | 68.6 |
| 60 | 66.7 | 68.2 | 68.5 | 69.4 | 69.6 | 69.6 | 69.6 | 69.6 | 69.1 | 67.5 | 65.5 | 66.9 |
| 75 | 65.3 | 66.7 | 68.7 | 69.5 | 69.8 | 69.8 | 69.8 | 69.8 | 69.3 | 67.9 | 64.2 | 65.2 |
| 90° (N-S) | 64.9 | 66.9 | 68.8 | 69.7 | 69.8 | 69.8 | 69.8 | 69.7 | 69.4 | 68.3 | 63.7 | 64.6 |

Total Radiation Reading Floor Area (cal/cm$^2$/day) Table 7

| Aspect | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0° (E-W) | 34 | 62.5 | 120 | 189 | 250 | 272 | 251 | 208 | 160 | 90 | 44.8 | 27.1 |
| 15 | 34 | 62.6 | 120 | 190 | 253 | 277 | 255 | 210 | 160 | 90 | 44.9 | 27.2 |
| 30 | 33.8 | 62 | 119 | 193 | 257 | 281 | 258 | 213 | 161 | 88 | 44.5 | 27.0 |
| 45 | 33.4 | 60.5 | 117 | 195 | 259 | 283 | 260 | 214 | 162 | 87 | 43.5 | 27 |
| 60 | 32.5 | 61.3 | 120 | 196 | 261 | 285 | 261 | 216 | 163 | 87 | 42.2 | 26.0 |
| 75 | 31.8 | 60 | 120 | 196 | 261 | 286 | 262 | 216 | 164 | 88 | 41.4 | 25.3 |
| 90° (N-S) | 31.6 | 60.1 | 120.3 | 197 | 261 | 286 | 262 | 216 | 164 | 88 | 41.1 | 25.1 |

## 3. Discussion of Results

The first requirements in devising a method of calculation for glasshouse light transmission were that it should produce consistent results, with no obvious contradictions, and that these should agree closely with previous measurements, where these were available. No internal inconsistencies in the calculation have so far been discovered, and the results set out above agree very closely with previous measurements where these are available. The difference between measured and calculated results is usually below 2% in the case of % transmission either of direct diffuse, or total light. It would be profitless to speculate which of the results is the more accurate in any one case, because both the measurement and calculation methods have some weaknesses, and further development of both or either may lead to even better agreement. Meanwhile, in the discussion which follows, the calculated results are assumed to be valid, so far as they relate to % transmissions. The absolute figures for total radiation at floor level involve the use of a constant of proportionality derived from observations at Kew, and applied to calculate the total value of diffuse radiation. Similar observations from other centres are unavailable, but it may be that these would result in different, and most probably higher values for diffuse radiation. The absolute figures given for total radiation reaching floor level therefore may be a slight understatement of the real values.

(a) The results firstly demonstrate the wide range of winter light transmission to be obtained by varying the construction and orientation of single glasshouses. For the month of January, the range from the worst to the best cases considered (timber house N-S and alloy wide-span E-W) is as follows:-

| | |
|---|---|
| % Transmission of Direct Light | 42% - 65.7% |
| % Transmission of Diffuse Light | 56% - 71.7% |
| % Transmission of Total Light | 52% - 69.8% |
| Total Radiation at Floor, cal/day/cm$^2$ | 25.3 - 34 |

The range of 8.7 cal/day/cm$^2$ obtainable between the best and worst cases considered is roughly equal to 6 hrs. of supplementary illumination daily at 500 H/sq. ft., or 3 hrs. at 1000 1/sq. ft., and would obviously have considerable effects on plant growth in this month. The increment available between best and worst examples in March is greater still, at 20 cal/day/cm$^2$.

It is important to note that this range of results is obtained at a latitude of 51°N, and in the sort of cloud/clear sky ratios which occur at Kew. A wider range still will be likely to occur in areas where cloudiness is less (in coastal areas especially). Moreover, this range occurs where weather conditions are those of the

ten year average: in years where sunlight hours are greater than average, the range of results will be greater. Further examples illustrating these effects are to be published later.

(b) The results demonstrate that of the advantage in winter light transmission gained by the best over the worst example, about two-thirds results from improved construction, and one-third from orientation. The cases so far covered do not give very much information on the effect of glasshouse shape, and this is to be studied further.

(c) The examples so far studied are perhaps most interesting in showing the effects of orientation. It has been demonstrated previously that an exact E-W orientation is ideal for winter light transmission, and there has been a tendency to overestimate the loss in transmission due to deviation from this orientation. In fact, the transmission losses in both examples are negligible where the orientation is up to 15° from E-W, and are quite small even at 30° from E-W. Thereafter the transmission falls quickly. This effect is shown in fig. 1., attached. It is interesting to note that during midwinter the roof surfaces are less sensitive to orientation away from true E-W than the wall surfaces. Fig. 2 shows this difference in the wide-span house in January. Transmission through the south wall falls away sharply between 15° and 30°, whereas the south roof continues to transmit at almost the same level until the orientation exceeds 45° from E.W. In view of the fact that transmission through a horizontal surface is unaffected by orientation, it is evident that the effect of orientation must increase as the surface is raised through intermediate angles to the vertical, but it is perhaps unexpected that the variation in transmission would take quite this form. The implication is that the greater the ratio of wall/roof surface, the more sensitive the house will be to orientation. It is hoped in further studies to look at the effect of varying roof pitch on transmission.

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References


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(3) Transmission of solar radiation by glasshouses. R. I. Edwards Exp. Hortic. 1963. 9. (1).

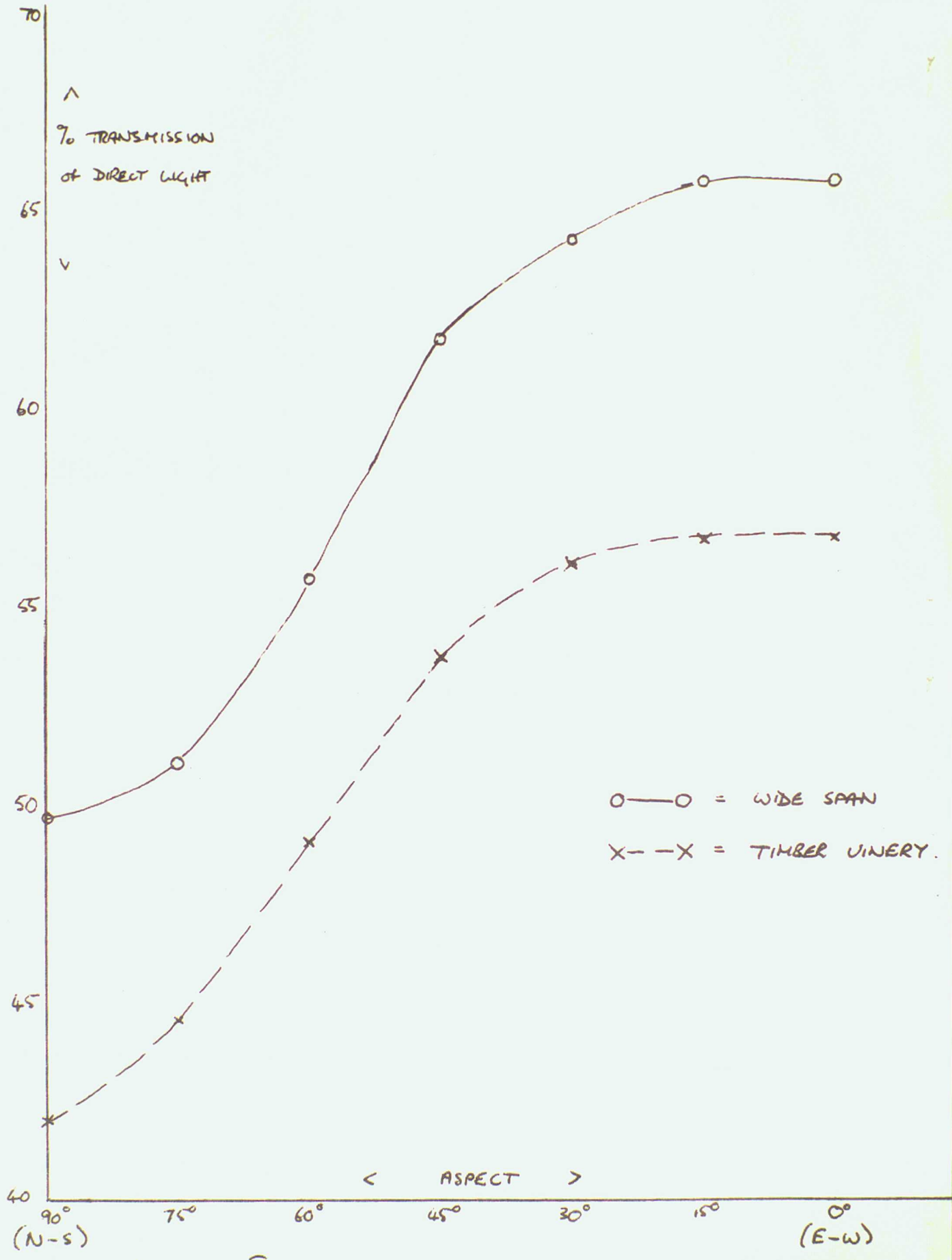
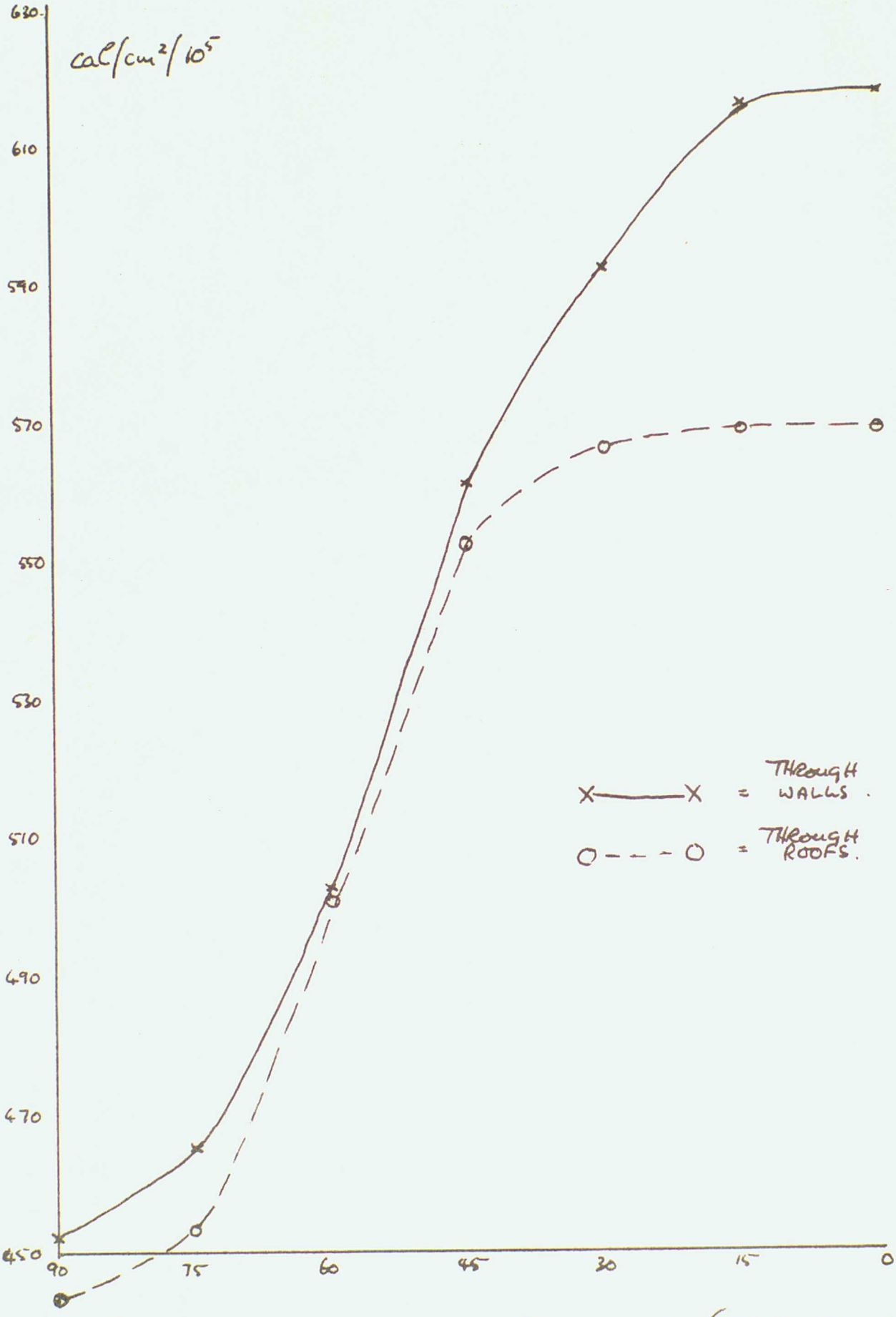



FIG 1. % TRANSMISSION OF DIRECT LIGHT IN JANUARY




DIRECT RADIATION TRANSMITTED TO FLOOR AREA (WIDE-SPAN HOUSE) AT DIFFERENT ORIENTATIONS IN JANUARY

FIG 2.